Comprehensive Approach of Groundwater Resource Evaluation: A Case Study in the Chippewa Creek Watershed in Ohio[1]

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ABSTRACT. A groundwater resource evaluation of Chippewa Creek watershed in Wayne and Medina counties, OH, shows continued availability of groundwater for agriculture and domestic uses. Two major hydrogeologic units in this watershed supply groundwater. A 100 to 150 ft (30 to 46 m) thick outwash deposit of sand and gravel, occupying a buried valley underlying Chippewa Creek, forms a highly permeable aquifer for agricultural, municipal, and domestic purposes. In some areas bedrock aquifers, mostly composed of sandstone of Pennsylvanian and Mississippian age, are used for industrial and domestic purposes. Mean transmissivity of the outwash aquifer is 25,000 gpd/ft (310 m^2/day). The hydraulic conductivity of the aquifer has a mean value of 250 gpd/ft^2 (10 m/day). The total calculated volume of annual net recharge is 4.2×10^8 ft^3 (1.2 10^7 m^3) and the mean specific capacity of the wells completed in aquifer is 5.0 gpm/ft (1.03 l/sec/m). The groundwater quality is suitable for drinking and agricultural use and contains mostly Ca^{++}, Na^+, K^+ and HCO_3^- ions. Groundwater pollution potential of the study area was evaluated using DRASTIC. Chippewa Creek watershed lies within the Glaciated Central Ground Water Region. Seven mappable units from DRASTIC were defined in the study area based on seven hydrogeologic settings. The units are: 1) 7Aa, glacial till over bedded sedimentary rocks (DRASTIC designation); 2) 7Ad, glacial till over sandstone; 3) 7Af, sand and gravel interbedded in glacial till; 4) 7Ba, outwash; 5) 7D, buried valley; 6) 7Eb, alluvium without overbank deposits; 7) 7Ec, alluvium over bedded sedimentary rocks. The outwash aquifer has a moderate to high pollution potential and the underlying sandstone and shale deposits show relatively low pollution potentials. The alluvium in valleys exhibits moderately high susceptibility to contamination.

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INTRODUCTION

The importance of ground water resources is already well established. Severe restrictions on the availability of surface water have caused more people to depend on ground water. Point and non-point sources of contamination have severely limited the availability of subsurface water resources in both the urban and the rural areas of the United States. As a result, the search for new aquifers has increased considerably in the past 20 years, particularly in farmland communities. A major problem in this effort is that potential areas of ground water resources may also be found to be the most vulnerable areas of contamination. Therefore, any attempt for ground water resource estimation in an area must be accompanied by a comprehensive study of contamination potential of the aquifer. Otherwise, from an economic standpoint, a successful aquifer delineation today may become an ultimate failure in the future.

Objectives

The Chippewa Creek watershed in Ohio includes a glacial aquifer of high resource potential, which may serve as a source of water for drinking and for other household purposes. A ground water resource investigation of the watershed was conducted with the following objectives:

1. To study the quality, occurrence, and development feasibility of ground water along the Chippewa Creek watershed in Wayne and Medina counties, OH. The vertical and the lateral extensions of the glacial aquifer were delineated, and its hydraulic properties and the volume of annual net recharge and yield were assessed. Major ion concentrations also were determined to characterize the existing quality of ground water.
2. To study the contamination potential of the aquifer. The DRASTIC (Aller and others 1987) method was applied to rank the vulnerability of the aquifer to contamination from surficial sources according to seven factors used in the method.

Description of the Study Area

The Chippewa Creek watershed lies on the glaciated, gently rolling Allegheny Plateau of northeastern Ohio. The area was covered by the Wisconsinan ice sheet that deposited a thick layer of glacial sediment, varying between 25 ft (8 m) and 200 ft (61 m) in thickness. The study area (Fig. 1) is drained by Chippewa Creek and flows southeastward. Its watershed is located in the Wayne and Medina counties, OH, approximately 15 to 20 mi (24 to 32 km) southwest of Akron, and covers approximately 15 mi^2 (39 km^2) area. Data on subsurface geologic materials and groundwater samples were collected from both the upland and the valley areas of the watershed, covering approximately 20 mi^2 (52 km^2) area. The study area has an agricultural land use where

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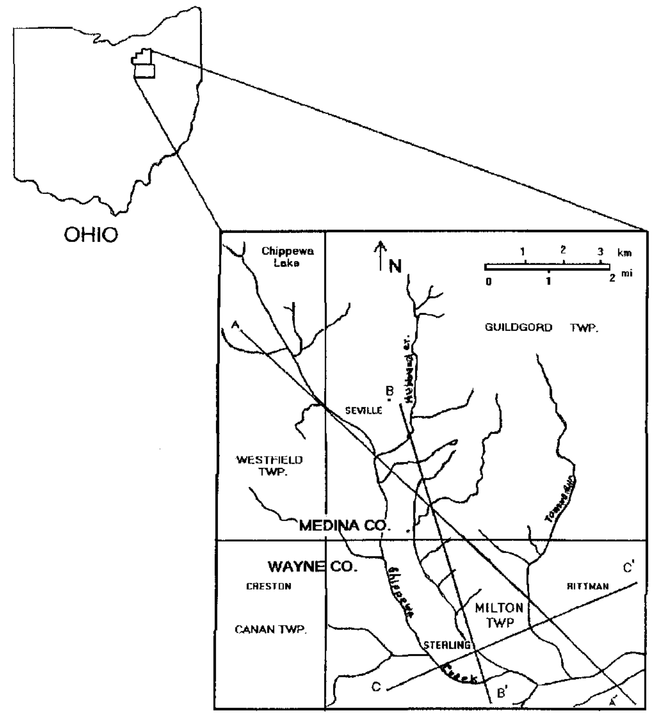

FIGURE 1. Location of the study area showing the section lines for the geologic cross sections.

commercial fertilizers are routinely applied to the cropped fields. The area is economically important because of its rich farmlands and expanding development of Seville and Rittman townships.

Soils of the area are nearly level to gently sloping and moderately well drained to well drained (Bureau and others 1984). They have developed in loamy materials overlying clayey glacio-lacustrine sediments or in loamy materials overlying sand and gravel (Hayhurst and others 1977; Bureau and others 1984). The average soil permeability ranges between 0.2 in (0.5 cm) to 6.0 in (15 cm) per hour (Bureau and others 1984).

The outwash deposits beneath the Wisconsinan till are 'clean' (White 1967) well-sorted sand and gravel that form an aquifer of potentially high yield beneath the study area. The ground water resources map of Wayne County by Crowell (1979) and the map of Medina County by Schmidt (1978) indicate that the buried valley aquifer underlying the Chippewa Creek is one of the best ground water areas in Wayne and Medina counties. The unconfined to semi-confined outwash aquifer is the primary source of drinking water in the area. The general direction of ground water flow is from northwest to southeast. The depth to groundwater table ranges from 30 to 75 ft (9 to 23 m) in the general area.

MATERIALS AND METHODS

Aquifer Delineation

Data from one hundred well logs were collected from the Ohio Department of Natural Resources (ODNR). These data were used to find the lateral and vertical dimensions of the outwash aquifer and its position beneath the ground surface. The location of each well was plotted on a base map using the ODNR and private well number and location. Then cross sections were drawn in north-south, northwest-southeast, and northeast-southwest directions based on the lithologic description of the well logs. Attempts were made to delineate clay lenses within and outside of the glacial aquifer. The lower boundary of the aquifer was determined to define any bottom confining layer other than the bedrock.

Hydraulic Properties

The hydraulic properties that were determined in this study include transmissivity (T), storativity (S), hydraulic conductivity (K), and specific capacity using well logs and modified Theis equation (Theis and others 1963). A BASIC computer program (Bradbury and Rothschild 1985) was used to calculate the hydraulic parameters. The general formula for estimating storativity (Todd 1980) was used to check the accuracy of analysis for storativity.

The annual net recharge rate was calculated from the equation, $R = TAS_y$, Where, R = recharge (m^3), A = area (m^2), T = thickness of the fluctuation zone (m), S_y = specific yield of the rock units within fluctuation zones (%). The lowest and highest monthly water level data were used to calculate the average range of fluctuation. For the fluctuation zones consisting of a single lithology, the specific yield value given by Walton (1962) was employed. But for multiple lithologies, the average specific yield was calculated.

Hydrogeochemistry

Eighteen ground water wells in the study area were sampled and analyzed for major anions and cations. Two samples were collected from each well. One sample was sealed immediately and refrigerated for anion analysis, and the other sample was acidified with double-distilled reagent grade nitric acid to protect the sample against ion exchange and to retain metals in solution for later analysis of cations by atomic absorption spectrophotometer. Temperature, bicarbonate alkalinity, specific conductance, and pH were measured in the field using standard procedures (Skougstad and others 1978). Hardness of the water was calculated by the following formula (Todd 1980):

$$\text{Hardness} = 2.5 * (Ca^{++}) + 4.1 * (Mg^{++})$$

The general groundwater type was determined by using Piper trilinear diagram (Piper 1953).

Evaluation of Ground Water Pollution Potential

The DRASTIC (Aller and others 1987) method was used to determine aquifer vulnerability to contamination from surface sources. This method was developed by the National Water Well Association for the US Environmental Protection Agency.

The DRASTIC system of mapping is divided into two basic tasks: defining an area's hydrogeologic setting by mappable units; and conducting relative ranking of those units by incorporating some hydrogeologic variables. The United States has been classified into 15 different and unique ground water regions (Heath 1984).

Within each region, numerous hydrogeologic settings can be identified and mapped.

With the DRASTIC method, the relative vulnerability of ground water contamination from surface sources is quantified considering seven hydrogeologic variables: 1) *depth* to water; 2) *recharge* rates; 3) the *aquifer* media; 4) the *soil* media; 5) *topography*; 6) the *impact* of the vadose zone; 7) the hydraulic *conductivity* of the aquifer. The hydrogeologic variables considered in this method are basic parameters that have been proven or are suspected to be probable indicators of the vulnerability of ground water supplies to contamination from surface sources. These factors, which form the acronym DRASTIC, are incorporated into a relative ranking scheme that uses a combination of weights and ratings (Table 1) to produce a numerical value called the DRASTIC index. The rating for each factor is selected based on available information and professional judgment. The DRASTIC Index (DI) is the weighted sum of seven factors that might affect the contaminant movement. The index is expressed as:

$$DI = D_R D_W + R_R R_W + A_R A_W + S_R S_W + T_R T_W + I_R I_W + C_R C_W$$

where the subscript R stands for rating, and the subscript W stands for weight. The calculated DI can be used to identify areas that are more susceptible to ground water contamination relative to other areas. The higher the DRASTIC index, the greater the vulnerability to contamination. The index generated provides only a relative evaluation tool and is not designed to produce absolute answers or to represent units of vulnerability.

RESULTS AND DISCUSSION

Aquifer Systems

The cross sections (Figs. 2,3) constructed from well logs demonstrated that the glacial aquifer has a depth ranging from 50 ft (15 m) to 150 ft (46 m) within the study area. Although the overlying till layer is nonuniform in thickness, the average depth to the aquifer (Fig. 4) over the central part is greater compared to the northwest and southeastern part of the area. The thickness of the aquifer ranges from 100 (30 m) to 150 ft (46 m). Maximum thickness of the aquifer is in the central part of the study area near Seville; the minimum thickness is towards the northern part of the study area. The overlying aquitard of till is composed largely of clay, gravel, and isolated boulders. The till is overlain by a thin veneer of Recent alluvium. The aquifer is separated

TABLE 1

Assigned weights and ratings for DRASTIC features.

DRASTIC Features													
Depth to water (ft)		Net Recharge (in/yr)		Aquifer Media		Soil Media		Topography (% slope)		Vadose Zone		Conductivity (gpd/ft²)	
Range	Rating	Range	Rating	Type	Rating	Type	Rating	Range	Rating	Type	Rating	Range	Rating
0-5	10	0-2	1	massive shale	2	thin/absent	10	0-2	10	confining layer	1	1-100	1
5-15	9	2-4	3	igneous/metamorphic (IM)	3	gravel	10	2-6	9	silt/clay	3	100-300	2
15-30	7	4-7	6	weathered IM	4	sand	9	6-12	5	shale	3	300-700	4
30-50	5	7-10	8	glacial till	5	peat	8	12-18	3	limestone	6	700-1000	6
50-75	3	10+	9	bedded Sst, Lst, shale	6	aggregated clay	7	18+	1	sandstone	6	1000-2000	8
75-100	2	—	—	massive sandstone (Sst)	6	sandy loam	6	—	—	bedded Lst, Sst, shale	6	2000+	10
100+	1	—	—	massive limestone(Lst)	6	silty loam	5	—	—	sand/gravel with clay	6	—	—
—	—	—	—	sand and gravel	8	clay loam	4	—	—	IM	4	—	—
—	—	—	—	weathered basalt	9	muck	2	—	—	sand and gravel	8	—	—
—	—	—	—	karst Lst	10	compact clay	1	—	—	karst Lst	10	—	—
Weight: 5		Weight: 4		Weight: 3		Weight: 2		Weight: 1		Weight: 5		Weight: 3	

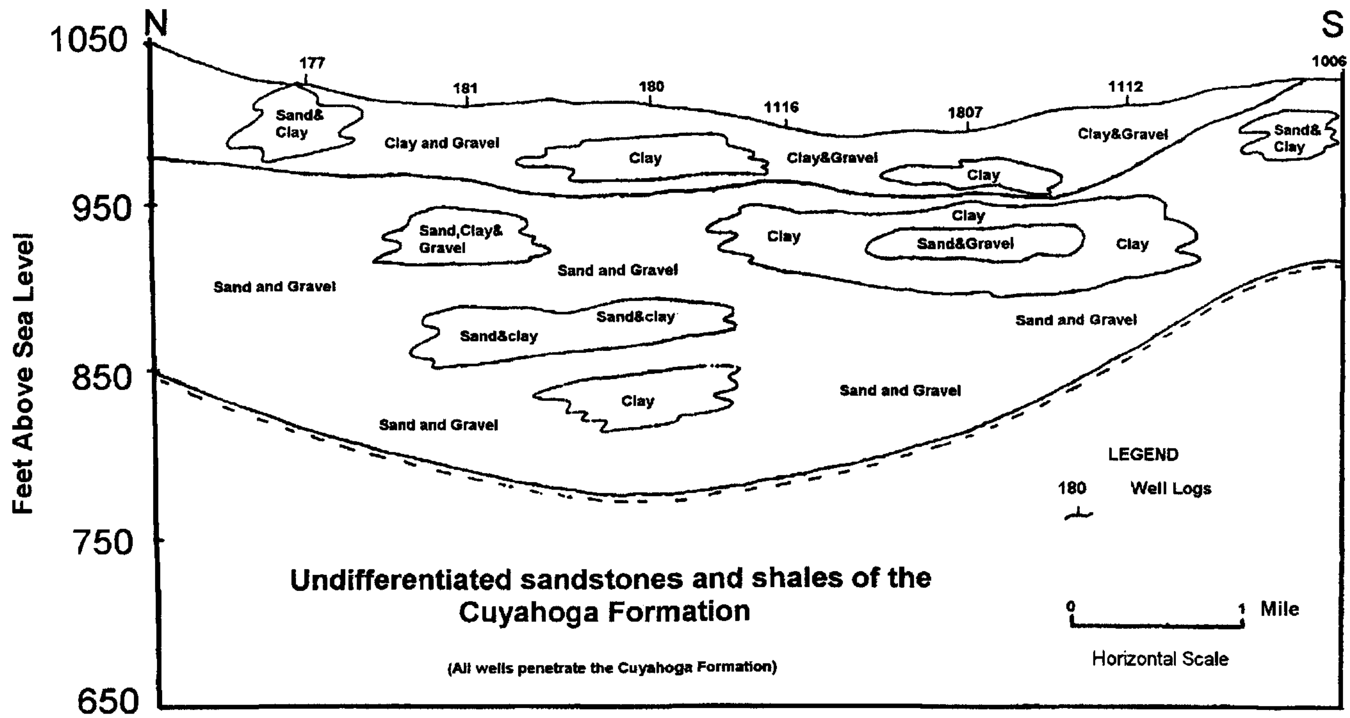

FIGURE 2. Geologic cross section along section line B-B', aquifer is located between dashed lines. Heavy line between bedrock and outwash aquifer indicates a 1-2 ft thickness of clay.

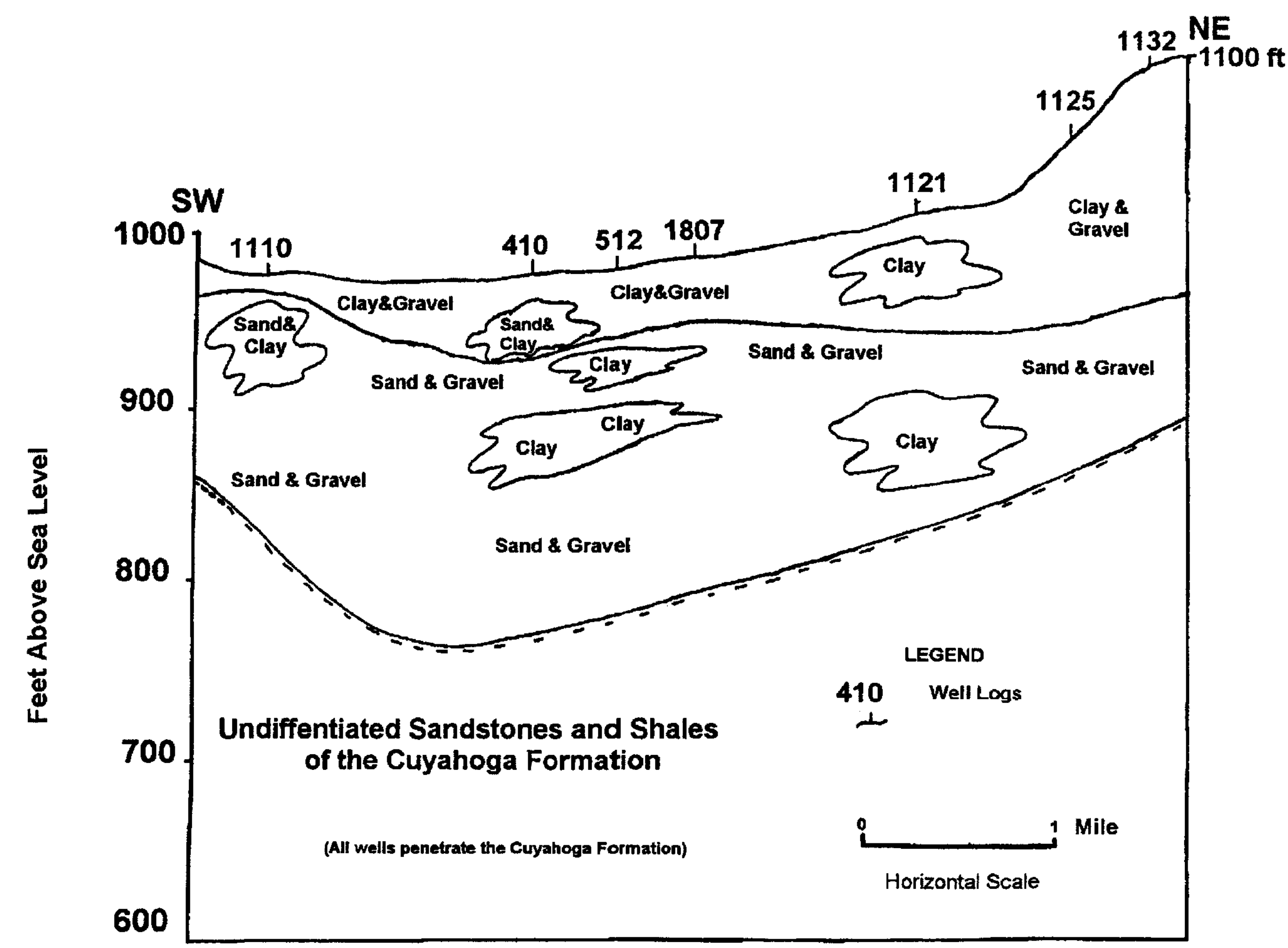

FIGURE 3. Geologic cross section along section line C-C', aquifer is located between dashed lines. Heavy line between bedrock and outwash aquifer indicates a 1-2 ft thickness of clay.

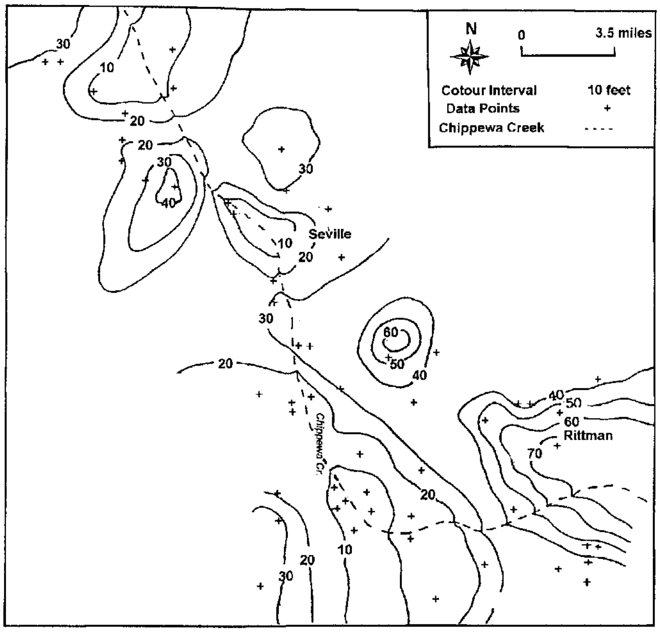

FIGURE 4. Depth to water table (ft) from land surface in Chippewa Creek watershed.

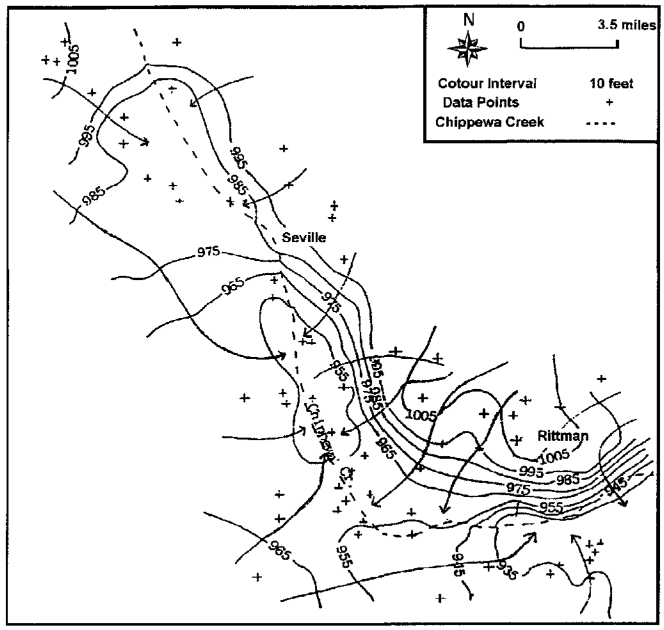

FIGURE 5. Groundwater elevation (ft) of Chippewa Creek watershed. Flow lines show a regional convergence of ground water from uplands to valley.

from the bedrock by a very thin impervious clay layer. The relatively clean nature of the outwash aquifer indicates that over 100 ft (30 m) of the aquifer is entirely screenable throughout the central and southeastern part of the area. Overall, it seems like the aquifer dimensions are quite favorable for its continued development in order to support the agriculture and domestic purposes in the area.

Hydraulic Properties

Most ground water wells in the study area are completed in the outwash aquifer. Transmissivity ranges from 400 gpd/ft (5.0 m^2/day) to 130,000 gpd/ft (1600 m^2/day) and has a mean of 25,000 gpd/ft (320 m^2/day). The central part of the study area near Seville has the highest average transmissivity, exceeding 30,000 gpd/ft (370 m^2/day). Hydraulic conductivity ranges from 4.0 gpd/ft^2 (0.16 m/day) to 1,300 gpd/ft^2 (53 m/day), averaging 250 gpd/ft^2 (10 m/day). Again, the central part has the highest hydraulic conductivity in the area. The mean specific capacity of wells in the aquifer is 5.0 gpm/ft (1.03 l/sec/m), ranging between 0.2 gpm/ft (0.04 l/sec/m) and 30 gpm/ft (6.2 l/sec/m).

The observed hydraulic parameters indicate a good response of the aquifer to pumping. Particularly, the hydraulic conductivity and the transmissivity values indicate that the aquifer has good potential for local agricultural purposes as well as municipal water supply. Most well test data demonstrate a drawdown of less than 10 ft (3 m) after continuous pumping of 3 to 4 hours; this indicates that the aquifer materials are highly conducive to groundwater production, making it a favorable area for well-field development. During pumping, the aquifer is readily replenished with ground water through lateral movement of water from adjacent areas. Even though there are scattered clay lenses in the aquifer, they do not seem to affect ground water production for local irrigation and water supply.

Groundwater Levels and Flow

Depth to ground water (Fig. 4) ranges from 70 ft (21 m) to the southeast near Rittman, to about 10 ft (3 m) to the northwest near Chippewa Lake. However, in the most part, depth to ground water ranges between 20 ft (6 m) and 30 ft (9 m). Considering the average depth to ground water in the area, particularly in the central and northwestern part, it is possible to exploit the aquifer with low capacity pumps anywhere in Guilford and Westfield townships (Fig. 1). Over the central and the northwestern part, the hydraulic gradient is much gentler

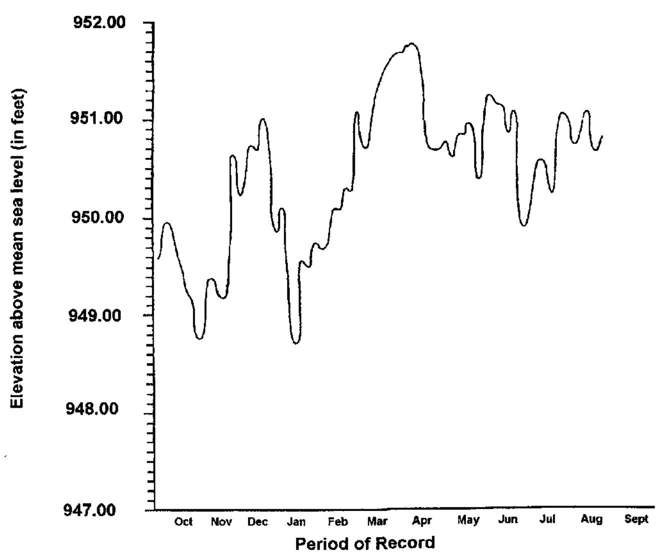

FIGURE 6. Average groundwater table throughout the year near Sterling in Seville (Oct. 1986 - Sept. 1987).

TABLE 2

Results of chemical analyses (ppm) of ground water samples from the Chippewa Creek watershed.

Well No.	Calcium (Ca^{++})	Magnesium (Mg^{++})	Sodium (Na^{+})	Potassium (K^{+})	Iron (Fe^{++})	Manganese (Mn)	Chloride (Cl^{-})	Sulfate ($SO_4^{=}$)	Nitrate (NO_3^{-})	Fluoride (Fl^{-})	Phosphate (PO_4^{-})	Alkalinity (HCO_3^{-})	pH	Temperature (° C)	Specific Conductance (mhos/cm)	Total Dissolved Solids (TDS)	Total Hardness (as $CaCO_3$)
36	120	25	61	2.1	0.1	0.1	140	88	0.1	0.11	0.05	280	7.2	23	950	570	400
52	44	18	94	3.4	0.1	0.0	31	61	0.4	0.27	0.34	320	7.7	25	760	410	180
72	99	38	54	5.1	0.1	0.0	35	170	0.2	0.17	0.04	320	7.3	25	1000	560	400
84	280	100	44	6.1	0.1	0.2	5	920	0.1	0.13	0.05	370	6.7	18	1800	1500	1100
97	120	25	13	1.6	0.1	0.1	65	121	0.2	0.10	0.04	210	7.0	25	770	450	400
98	19	7	220	4.5	0.1	0.0	150	68	0.2	0.39	0.04	350	7.7	25	1100	640	80
113	25	8	730	5.8	0.1	0.1	930	95	0.3	1.23	0.42	530	8.3	2	3900	2000	90
176	89	20	33	12.3	0.1	0.0	25	67	6.0	0.14	0.20	320	7.4	16	720	400	300
178	120	28	55	2.7	0.1	0.1	142	130	0.2	0.19	0.04	180	8.1	15	980	570	410
179	42	12	52	1.7	0.1	0.0	14	13	0.2	0.23	0.19	290	7.9	20	500	280	150
451	91	52	120	6.0	0.1	0.0	9	382	0.3	0.10	0.04	430	7.5	23	220	870	440
654	120	37	100	3.6	1.3	0.1	180	170	0.1	0.10	0.22	320	7.4	21	1300	770	450
1693	50	19	53	2.7	0.1	0.1	48	51	0.1	0.25	0.00	220	7.7	15	550	330	200
1808	36	13	48	2.3	0.1	0.1	6	16	0.3	0.30	0.40	300	7.6	19	480	270	140
—	34	12	60	2.5	0.1	0.1	16	19	0.2	0.37	0.80	300	7.8	27	500	290	130
—	33	11	64	2.1	0.1	0.1	19	17	0.2	0.41	0.80	260	7.6	26	510	270	130
—	51	33	10	3.1	0.1	0.0	20	140	1.9	0.10	0.10	140	6.4	28	580	330	260
—	24	9	53	2.2	0.1	0.1	8	32	0.1	0.34	0.12	220	7.3	27	410	240	100

than the southeastern part, particularly near Rittman where the gradient is considerably steeper (Fig. 5). Flow lines constructed from the hydraulic head data demonstrate that ground water converges toward the valley from the uplands on both sides, and emerges mostly at and around the central part, near Seville. In general, a regional convergence occurs toward the central part of the study area. It appears that the Seville area is the best location for groundwater discharge. But the suitability of the southeastern and northwestern parts for groundwater production also remains good for local agriculture and water supply.

The daily groundwater levels recorded by ODNR near Rittman and Seville show an annual water table fluctuation of about 8.0 ft (2.5 m), but over most of the central part of the study area, a fluctuation of approximately 5.0 ft (1.5 m) has been noted. The water table gradually attains its average highest position during April-May and takes its lowest position during January-February (Fig. 6). The entire study area has been divided into two parts for recharge quantification, the Rittman subarea and the Seville subarea. The Rittman subarea has an estimated average specific yield within the fluctuation zone of 10%. The typical lithology within the fluctuation zone is sand and clay, and by using equation 6, the annual recharge quantity is 1.7×10^8 ft^3 (4.7×10^6 m^3). The Seville subarea has an estimated average specific yield within the fluctuation zone of 15%. The typical lithology within the fluctuation zone is sand, and the annual recharge is 2.5×10^8 ft^3 (7.08×10^6 m^3). The total

FIGURE 7. Groundwater pollution potential map of Chippewa Creek watershed, Wayne County, OH.

calculated volume of annual recharge is 4.2×10^8 ft^3 (1.2×10^7 m^3), which is considered very high. Because of the subsurface continuity of the aquifer, this volume is easily exploitable from almost any location in the study area. Regionally, uplands are areas of ground water recharge; the valley, which also has significant vertical recharge, is the area of ground water discharge.

Hydrogeochemistry

The analyzed samples represent ground water from both the valley and the uplands, ranging in depth from 60 (18 m) to 130 ft (40 m) from surface. No appreciable change in chemistry is observed across the study area, and the average values of the constituents (Table 2) in the watershed show that the major cations and anions are below the maximum contaminant levels (MCLs) as recommended by the USEPA (1994). The water is of good quality in terms of drinking standards; total dissolved solids (TDS) are less than 1,000 mg/L in most of the wells, and in 50% of the wells, it is less than 500 mg/L. The outwash aquifer is very clean in terms of agricultural leachate, such as nitrate. In 90% of the wells, nitrate concentration is less than 1 mg/L. The highest concentration is 6.0 mg/L which is still less than the natural background concentration limits (≈10 mg/L). Overall, the observed chemistry suggests that the outwash aquifer is not only highly productive in terms of the volume of water available, but also it has potential as a continuous source of drinking water. Because the area is still in expanding stage for large scale farming and expanding urban activities, no adverse effect has yet been imposed on the water quality, but south in Seville merits monitoring.

Groundwater Pollution Potential

A groundwater pollution potential map (DRASTIC map) was prepared for Chippewa Creek watershed (Fig. 7). DRASTIC was used to evaluate the relative susceptibility of the area to any contaminant that has the mobility of water. Seven hydrogeologic settings were identified in the area with groundwater pollution potential indexes ranging from 88 to 187 (Table 3). The entire area is covered by variable thicknesses of glacial till and outwash sands and gravels that have a moderate to high pollution potential index (Fig. 7). The study area has a buried valley underlying the Chippewa Creek, which constitutes a major groundwater resource, and exhibits a moderate to high vulnerability to contamination. The glacial deposits are underlain by sandstone and shale sequences, and show relatively low pollution potential. Pollution potential indexes of areas containing recent alluvium in valleys exhibit moderately high susceptibility to contamination.

CONCLUSION

♦The Chippewa Creek watershed of Wayne and Medina counties of Ohio is underlain by a 100 ft (30 m) thick, highly permeable, outwash aquifer. The hydraulic parameter values are very high, suggesting that the aquifer is capable of being a continuous source of groundwater for agriculture and municipal purposes.

TABLE 3

Hydrogeologic settings mapped in the study area for DRASTIC.

Hydrogeologic Settings	DI Ranges	No. of Index Calculations
7Aa-Glacial Till Over Bedded Sedimentary Rocks	78 – 150	37
7Ad-Glacial Till Over Sandstone	79 – 158	33
7Af-Sand&Gravel Interbedded in Till	88 – 152	23
7Ba-Outwash	107 - 179	19
7D-Buried Valley	111 - 179	26
7Eb-Alluvium Without Overbank Deposits	95 - 160	35
7Ec-Alluvium Over Bedded Sedimentary Rocks	90 - 138	5

♦There is no significant variation in water quality across the study area, and the water is suitable for drinking and agricultural uses.

♦DRASTIC determined that potential for groundwater contamination is highest along the Chippewa Creek, indicating that the underlying outwash aquifer is quite vulnerable to contamination.

♦This investigation determined that a comprehensive evaluation of an aquifer for development should include not only its dimensions and hydraulic properties but also its long-term susceptibility to contamination.

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